



**A Prototype Overview for Allocating USAID  
Foreign Aid**

THESIS

Deane E. Cover, Captain, USAF

AFIT-OR-MS-ENS-12-08

**DEPARTMENT OF THE AIR FORCE  
AIR UNIVERSITY**

**AIR FORCE INSTITUTE OF TECHNOLOGY**

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**Wright-Patterson Air Force Base, Ohio**

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A Prototype Overview for Allocating USAID Foreign Aid

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Deane E. Cover, BS

Captain, USAF

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Deane E. Cover, BS  
Captain, USAF

Approved:

\_\_\_\_\_  
// SIGNED //  
Dr. Richard F. Deckro  
(Chairman)

20 April 2012  
date

\_\_\_\_\_  
// SIGNED //  
Dr. Jeffery D. Weir  
(Member)

20 April 2012  
date

Abstract

The United States Agency for International Development (USAID) is the federal government agency primarily responsible for administering civilian foreign aid. In fiscal year 2011, USAID spent approximately \$15 billion in an effort to assist countries recovering from disaster, trying to escape poverty, and engaging in democratic reforms. Using Value-Focused Thinking, regression, and optimization techniques, this thesis utilizes overarching USAID objectives and underlying policy to develop a prototype overview model that maybe used to provide insight to a Decision Maker regarding how changes in funding allocation can lead to improved impact.

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*To My Wife*

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Deane E. Cover

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# A PROTOTYPE OVERVIEW FOR ALLOCATING FOREIGN AID OF USAID

## I. Introduction

### General Issue

Although the concept of foreign aid has been a political and social tool since ancient times, the scope and magnitude of its usage was greatly increased with the end of World War II and the onset of the Cold War. Due to the devastation of the war as well as the looming Cold War threat of the Soviet Union, it was recognized that the need for global reconstruction while advancing democratic interests was never greater as evidenced by the Marshall Plan. In 1961 President John F. Kennedy created the United States Agency for International Development (USAID) to implement the Foreign Assistance Act of 1961. To this day, USAID has “promoted democratic interests while improving lives in the developing world” (About USAID, 2011).

In fiscal year 2011, USAID spent approximately \$15 billion in an effort to “assist countries recovering from disaster, trying to escape poverty, and engaging in democratic reforms” (About USAID, 2011). As with any federal agency, there is concern that taxpayer dollars are being put to good use. This is especially true now with the recent economic downturn. This thesis used the concept of Value-Focus Thinking (VFT), as defined by Dr. Ralph L. Keeney, to take USAID objectives and underlying policy to develop a model that reflects the “values” of USAID (Keeney, 1992). Using the concepts of regression and optimization, starting allocations were varied so that impact is

improved, as measured by the value model. This prototype model was then used to generate insight with regards to the decision context.

### **Previous Research**

USAID has published an Annual Performance Report (APR) since 1995 that can be accessed at its website (USAID: Performance and Accountability, 2011). The APR “[...] presents a detailed assessment of Agency performance against annual targets for a representative set of foreign assistance indicators” (USAID: From the American People, 2012). It defines a set of “indicators” which are measures of performance for the USAID objectives reflecting U. S. Foreign Policy at that time. Some examples from FY 2009 APR are hectares of drug crops eradicated in U.S.-assisted areas as an indicator for the Peace and Security objective and number of people receiving HIV/AIDS treatment as an indicator for the Investing in People objective. The APR gives the progress made by each indicator towards a target value. These results are used as a justification for future funding allocation.

### **Problem Statement**

In its policy, USAID has listed a number of high-level objectives that express what the agency values. With the objectives are listed some specific goals that suggests how these objectives might be measured. While there has been some effort to examine how much progress has been made with regards to meeting these goals, an analysis has not been conducted that focuses directly on what the agency “values” to gain insight on how it should allocate its funding based on these values. In his book *Value-Focused Thinking*, Keeney introduces a methodology that can assist in accomplishing such an analysis (Keeney, 1992).

## Research Objective

The purpose of this thesis was to develop and utilize a first-cut, overview model to gain insight on how USAID funding allocation can better satisfy the values of the agency and thus the United States government. The values of USAID were derived from its objectives and underlying policy.

## Methodology Overview

The VFT process was used to clarify, organize, and quantify the values of USAID. A diagram of the 10-step VFT process is shown in Figure 1.

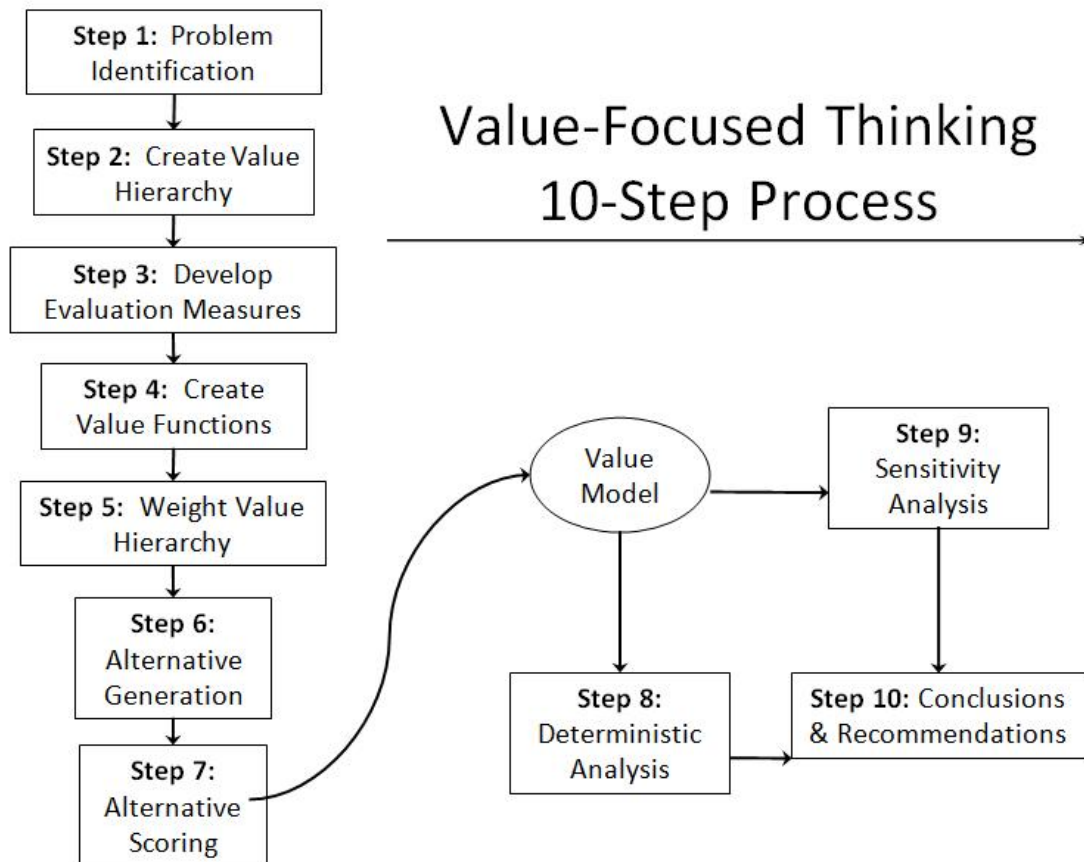


Figure 1. VFT 10-Step Process Flow Chart (Shoviak, 2001)

The process is typically used for decisions with a discrete set of alternatives. Since funding allocations can take on any value between zero and one (0% and 100%), the model for this thesis has a continuous set of alternatives. For this reason, regression and optimization were used to complete the model. The use of these two concepts is explained in relation to the VFT 10-Step Process.

***Steps 1, 2, 3, and 4.***

Taking USAID's overarching goal "to shape and sustain a peaceful, prosperous, just, and democratic world and foster conditions for stability and progress for the benefit of the American people and people around the world" and its Seven Core Development Objectives, a fundamental objectives value hierarchy was created with mutually exclusive and collectively exhaustive objectives (USAID Policy Framework 2011-2015, 2011). For the lowest tier of objectives, measures were identified so that an additive value model could be generated. For each measure, annual measure quantities were found and linked to the funding allocation for that year. Regression was performed on this performance data to produce response functions that were used to estimate a measure quantity (output) given an allocation (input). The terms measure quantity and quantity are used interchangeably throughout this thesis.

***Steps 5, 6, 7, and 8.***

Using funding requests by program area from the *Congressional Budget Justification Foreign Operations Annex: Regional Perspectives* for FY 2012, weights were determined and used as coefficients in the additive value function (Congressional Budget Justification: Foreign Operations). Appendices A and B provide complete hierarchies including weights (global and local respectively). The weighted value

function was then used to evaluate changes in funding allocation within an optimization. The optimization varied allocations to maximize the additive value function. The response functions were used within the optimization to convert an allocation into a measure quantity. Since funding allocation involves continuous alternatives, no new alternatives were generated per se.

***Steps 9 and 10.***

Levels of overall funding were varied to provide insight to the Decision Maker (DM) regarding how different levels of funding can impact the value function score. The output from the optimization quantified the impact of varying allocations.

Chapter 2 of this thesis consists of a literature review. Primarily, VFT, regression, and optimization as they apply to the study will be explained in greater detail. Chapter 3 consists of a detailed explanation of the methodology behind this analysis. Chapter 4 consists of the model being applied to the nation of Georgia. Chapter 5 concludes the thesis with a general discussion of results and assumption.



## II. Literature Review

### Value-Focused Thinking

In their text *Making Hard Decisions*, Clemen and Reilly define Decision Analysis (DA) as something that provides “[...] structure and guidance for thinking systematically about hard decisions [...]” and “[...] insight about the situation, uncertainty, objectives, and trade-offs” (Clemen & Reilly, 2001, pp. 2,4). The purpose of DA is not just to find a “good” solution for the Decision Maker (DM). It is to illuminate the decision situation so the DM can make a more informed decision. Value-Focus Thinking (VFT) is one of many DA processes that can be used.

In his book *Value-Focus Thinking: A Path to Creative Decisionmaking*, Keeney defines VFT by comparing it to alternative-focused thinking (Keeney, 1992). Alternative-focused thinking bases a decision on picking the “best” alternative from a group of alternatives. It does not take into account what is a good decision for the DM. The group of available alternatives could consist entirely of what the DM would consider bad alternatives. VFT instead focuses on the values of the DM or organization. It requires a definition of what is valued in the decision context. By focusing on values, VFT can identify good alternatives. Figure 2 shows an overview of VFT:



Figure 2. Overview of VFT (Keeney, 1992, p. 24)

The VFT process should not only consider current alternatives, but provide a forum for creating new alternatives. This is intended to promote creativity. It is not always a good idea to wait for a decision opportunity to present itself. Identifying decision opportunities is a proactive way to improve upon the “status quo.” As a byproduct of illuminating a specific decision context, VFT can guide the overall strategic thinking of an organization. Inter-connecting decisions is an important way to ensure selecting an alternative for one decision does not negatively affect a different decision outcome. Or if it does, any negative effect is at least taken into account when evaluating all related decisions as a whole. Once all values are identified in a decision context, it should be easier to find measures to evaluate alternatives. In this way, VFT guides information collection. Many decisions involve multiple stakeholders that must interact

to choose an alternative. VFT can facilitate the involvement of these groups when interacting so that values can be clearly stated and disagreements can be mediated. This process can also improve communication amongst stakeholders and the DM by forcing them to express what they consider important in the decision situation. By eliciting values and determining a way to quantify those values, alternatives can be evaluated for the DM. For anyone involved in a decision situation, it is possible that the true underlying values are unknown. Sometimes a decision is made based on a gut feeling. Helping everyone involved to articulate their values can lead to uncovering hidden objectives.

For the scope of this thesis, only three of the items mentioned in Figure 2 were pertinent to the context. The USAID VFT model was used to guide data collection and evaluate alternatives. Measures were found based on USAID's stated values (USAID Policy Framework 2011-2015, 2011) that showed where a DM could look for data to quantify said values. Continuous alternatives (allocations) were evaluated using an additive value function, regression, and optimization (discussed in more detail later in this section). The purpose of the model is to guide strategic thinking by providing insight to a DM.

In order for VFT to be effective, it must follow some basic tenets. From Kirkwood, we are given the Axioms of Consistent Choice (Kirkwood, 1997, p. 268).

Here, “>” means “is preferred to” and consequences of decisions are designated

$c_1, c_2, \dots c_n$ .

1. Transitivity: If  $c_i > c_j$  and  $c_j > c_k$  then  $c_i > c_k$

2. Reduction: If the standard rules of probability can be used to show that two alternatives have the same probability for each  $c_i$ , then the two alternatives are equally preferred
3. Continuity: If  $c_i > c_j > c_k$ , then there is a  $p$  such that an alternative with a probability of  $p$  of yielding  $c_i$  and a probability of  $1 - p$  of yielding  $c_k$  is equally preferred to  $c_j$
4. Substitution: If two consequences are equally preferred, then one can be substituted for the other in any decision without changing the preference ordering of alternatives
5. Monotonicity: For two alternatives that each yield either  $c_i$  or  $c_j$ , where  $c_i > c_j$ , then the first alternative is preferred to the second if it has a higher probability of yielding  $c_i$

The axioms ensure that elicited preferences are not self-contradictory in nature.

Parnell has defined a set of structured techniques that are applied to value modeling. These techniques classify how the analyst elicits values from the DM or organization. Table 1 gives definitions for the Gold, Silver, Platinum, and Combined Standard techniques.

Gold	"[...] depends on an approved vision, policy, strategy, planning, or doctrine document."
Silver	"[...] uses data from the stakeholders' representatives."
Platinum	"[...] depends on interviews with decision makers and stakeholders."
Combined	"Sometimes, we can combine standards."

Table 1. Value Model Techniques (Parnell, 2007, p. 8)

He recommends that the analyst should "[...] begin developing a value model by researching potential gold-standard documents" but eventually should "[...] confirm with

senior leaders that each document still reflects leadership values” (Parnell, 2007, p. 8).

This thesis made use of the Gold Standard as a first step in assisting USAID.

Keeney discusses structuring values (what he calls objectives) when he states “the process of structuring objectives results in a deeper and more accurate understanding of what one should care about in the decision context” (Keeney, 1992, p. 69). He goes on to suggest using what he calls a fundamental objectives hierarchy as a way of giving structure to the decision context. This hierarchy provides a variety of benefits. It can point out values and alternatives that are not being considered. The hierarchy can be used to facilitate communication between the analyst, DM, and SME. It can clarify terminology with regards to the context. It can be used to better define the importance of values relative to one another. It can be used to identify the most basic values important to the context which are in turn used to find measures. This thesis made use of the last three of these benefits.

To maximize the benefit derived from a VFT model, any tier of the hierarchy should encompass all values that are pertinent to the context (collectively exhaustive). To reduce ambiguity, the hierarchy is structured so that there is no overlap amongst values within a tier (mutually exclusive). In his book *Strategic Decision Making*, Kirkwood defines a tier as “[...] evaluation considerations at the same distance from the top of a value hierarchy [...]” (Kirkwood, 1997, p. 13). Since this thesis presents its hierarchy vertically, this definition translates to distance from the left.

Following the order of events in Figure 1 (10-Step Process), measures are determined to quantify the lowest-tier values of the hierarchy. It is important that data for the measures can be attained and that the data is easily interpreted. Kirkwood is referring

to this latter point when he defines the clairvoyance test as someone being “[...] able to unambiguously assign a score to the outcome from each alternative [...]” (Kirkwood, 1997, p. 28). By “score” he is referring to a measure quantity. Kirkwood also mentions a way of classifying measures into four groups. Table 2 shows the four classifications along with an order of preference. Table 3 gives a definition of the terms.

	Natural	Constructed
Direct	1	2
Proxy	3	4

Table 2. Measure Classification (Kirkwood, 1997)

Natural	"[...] in general use with a common interpretation by everyone."
Constructed	"[...] developed for a particular decision problem [...]"
Direct	"[...] directly measures the degree of attainment [...]"
Proxy	"[...] reflects the degree of attainment of its associated objective [...]"

Table 3. Classification Definitions (Kirkwood, 1997, p. 24)

Measures can be natural or constructed, direct or proxy. Given the nature of the problem, many of the measures in this study are proxy measures.

For a value model it is necessary to combine all measure quantities for a given alternative so that an overall score can be determined. The immediate problem that presents itself is trying to combine varying units. For example, how do you combine square feet and degrees Celsius? An option would be to simply normalize. This could be done by determining the progress a quantity has along a path from the least to the most preferred quantity in the form of a proportion. Although this addresses the units issue, it does not address the fact that increments in value often vary as quantities travel from least to most preferred. A measure might yield a small increase in value until a threshold is met at which point value increases dramatically. Conversely, value might increase

dramatically until a goal is reached at which point it yields a small increase. This is referred to as increasing and decreasing returns to scale respectively.

Kirkwood defines a single-dimensional value function (SDVF) as a “[...] function over each evaluation measure that accounts for the returns to scale before combining the evaluation measure scores” (Kirkwood, 1997, p. 60). Again, by “score” he means a measure quantity. Typical forms for a continuous SDVF are linear, exponential (concave and convex), and *S*-curve. A SDVF must be monotonic but does not have to be smooth (can be piecewise). Since measure quantities can be categorical, a SDVF can be categorical. The output of a SDVF falls between zero and one. The zero corresponds to the least preferred measure quantity and one corresponds to the most preferred. How the shape of the SDVF is found depends on the technique used (Gold, Silver, or Platinum). For the Silver and Platinum standards, the shape can be elicited from a DM or SME. A set of measure quantities and their corresponding values can be obtained. For continuous measures, this should include the most preferred (value of one), least preferred (value of zero), and one measure quantity in between the two. The third measure quantity can be obtained by asking for a “50%” or “80%” solution (quantity that gives 0.5 or 0.8 values respectively). From here, one of the above mentioned forms is chosen to fit the data. For categorical measures, increments in value between measure quantities can be elicited to form the SDVF. Since this thesis used the Gold Standard, measure goals, thresholds, and the context found in policy and documentation were used to define SDVFs.

Given that measure quantities can be combined, it is necessary to decide how they will be combined. Weights are proportions falling between zero and one that express how each value contributes to the overall decision being made. The hierarchy is used

when determining weights. Weights are applied to values (objectives) and measures in the hierarchy. The hierarchy as a whole should be collectively exhaustive. The weights of values falling beneath a parent value should sum to one (local weights). It also means the weights of measures should sum to one (global weights). Global weights can be calculated from local weights and vice versa. Multiplying local weights along a branch (direction perpendicular to a tier) will give the global weight for the resulting measure. Dividing a global weight by the sum of all global weights for that branch will give the local weight for that measure's parent value. This can be continued towards the fundamental objective until all global weights are calculated.

There are several ways to elicit weights from a DM or SME. One way would be to ask that measures be ranked in order of importance. Their importance relative to one another could then be elicited in the form of a multiple that represents how important a measure is in relation to the least important. For example, the cost of a home could be five times as important as the square footage for the buyer. For each measure, its corresponding multiple would be divided by a sum of all the multiples to get global weights. From there, local weights could be calculated. A similar process could be used to elicit local weights and calculate global weights. This method does not take into account the range of measure quantities (distance between least preferred and most preferred quantity) as specified by the DM. Using the house hunting example, it is possible that the buyer is only considering a price range of \$150K to \$170K (13% increase) whereas the square footage under consideration is 1000 to 2500 square feet (150% increase). Taking that into account, price might only be twice as important as square footage instead of five times as important. Intuitively, the smaller the range for a



measure the more likely its quantity for a given alternative will fall outside that range and therefore contribution to the value function score will either be a zero or one. In this way, the measure approaches being a binary value which makes it more of a constraint than a measure. Typically, constraints are not considered when scoring alternatives in a VFT model. The results of the model are presented to the DM and it is up to them to rule out alternatives based on constraints. For this reason, it is reasonable to say that the smaller the range for a given measure, the smaller its weight in the model. Using swing weights takes this phenomenon into account (Kirkwood, 1997).

Swing weights are simply weights that account the range of measure quantities. They can be attained a number of different ways. One way would be to have the DM imagine all measures at their least preferred level. Then he or she imagines each measure being raised to its most preferred level while keeping the others constant. Then have the DM rank and give multiples (same as for regular weights) for the measures based on that measure being raised to its most preferred level. This process will give global swing weights. For the USAID value model, weights were determined by reviewing the latest funding request for Georgia.

With SDVFs and weights determined, a value function must be chosen that will combine the two and output a single value so that alternatives can be evaluated. According to Parnell, the “[...] simplest and most common [...]” type of value function is the additive value function seen here (Parnell, 2007, p. 10):

$$v(x) = \sum_{i=1}^n w_i v_i(x_i)$$

$$\text{where } \sum_{i=1}^n w_i = 1, v_i(x_i) \in [0,1], \text{ and } n = \text{number of measures}$$

In order to use the additive value function, the assumption of mutual preference independence must be made. Kirkwood defines a set of measures as having mutual preference independence if “[...] Y is preferentially independent of Z for every partition {Y, Z} of {X<sub>1</sub>, X<sub>2</sub>, ..., X<sub>n</sub>}” where “[...] Y is preferentially independent of Z if the rank ordering of alternatives that have common levels for all attributes in Z does not depend on these common levels” (Kirkwood, 1997, p. 238). Here {X<sub>1</sub>, X<sub>2</sub>, ..., X<sub>n</sub>} is the set of all measures (which he calls attributes). Some other types of value functions that could have been used are the multiplicative and power-additive value functions (Kirkwood, 1997). For this first-cut overview model, it was decided to use the additive value function.

### **Decisions with Continuous Decision Variables**

Once SDVFs, weights, and the value function are determined, alternatives must be evaluated. Not all decision situations deal with a discrete set of alternatives. For example, an organization’s allocation of money or resources would most likely form continuous alternatives. An immediate solution might be to discretize the alternatives. However, this could be an oversimplification of the decision context.

In his book *Strategic Decision Making*, Kirkwood gives a method for modeling a decision situation where alternatives are continuous (Kirkwood, 1997). He recommends building a response function for each of the measures. This is done by finding measure quantities for discrete levels of the possible alternatives. For the funding allocation example, quantities would be found for a discrete set of differing allocations. A smooth

curve is “drawn” through these data points. The equation of this curve is our response function and is used thereafter to estimate a measure quantity given an input alternative. In his example, Kirkwood elicits three data points from the DM for each measure and identifies the second-degree polynomial function that intercepts the points to get his response functions. From here he finds the best alternative by using an Excel Data Table. This thesis did not restrict itself to using a quadratic response function. Since the number of data points varied, most of the response functions made use of regression to fit a line to the performance data. Occasionally, the response function was simply a graph thru the points. They range from first to fourth degree polynomials. In addition, this thesis finds an improved alternative (allocation) by optimizing with Excel 2010 Premium Solver Platform V11.5.

## **Regression**

In their book *Introduction to Linear Regression Analysis*, Montgomery, Peck, and Vinning discuss using polynomials to fit a line to data. Throughout the book they stress that linear regression should be used over the “[...] region of the regressor variables contained in the observed data” (Montgomery, Peck, & Vining, 2006, p. 3). This is referring to interpolation. The further one moves away from the range of data (extrapolation) the less likely the model will be “valid.” They go on to point out that, in general, a polynomial model’s degree should be kept as low as possible. They recommend starting with a first degree, then trying a transformation (exponential, logistic, etc.), then a second degree, and only using a third or higher degree if something external to the data justifies it. This thesis used a process of data mining to determine response functions based on performance data. Data mining is simply “the application of

specific algorithms for extracting patterns from data” (Fayyad, Piatesky-Shapiro, & Smyth, 1996, p. 39). Starting with a first degree polynomial, the degree was increased up to a fourth degree and a comparison was made between all possible models. The values compared were *R*-squared, adjusted *R*-squared, and Mallows’  $C_p$  criterion. These values are defined as (JMP: Modeling and Multivariate Methods, 2010):

- *R*-squared : The proportion of the variation in the response that can be attributed to terms in the model rather than to random error.
- Adjusted *R*-squared: Adjusts *R*-squared to make it more comparable over models with different numbers of parameters by using the degrees of freedom in its computation. The adjusted *R*-squared is useful in stepwise procedure because one is looking at many different models and want to adjust for the number of terms in the model.
- Mallows’  $C_p$  criterion: It is an alternative measure of total squared error defined as

$$C_p = \left( \frac{SSE_p}{s^2} \right) - (N - 2p)$$

where  $s^2$  is the MSE for the full model and  $SSE_p$  is the sum-of-squares error for a model with  $p$  variables, including the intercept. Note that  $p$  is the number of  $x$  variables plus one. If  $C_p$  is graphed with  $p$ , Mallows recommends choosing the model where  $C_p$  first approaches  $p$  (Mallows, 1973).

No hard rule was followed when selecting a model. For larger data sets, Mallows’ criteria was observed first and then the other two values. For smaller data sets, *R*-squared and then adjusted *R*-squared were observed. Calculations were performed in JMP 8.0.2 by fitting a model with the macro polynomial to degree four applied to the single regressor, performing a stepwise regression, and looking at all possible models. In

addition, allocations were constrained when optimizing to minimize extrapolation by the response functions.

In *Consistency and Optimality in Managerial Decision Making*, Bowman discusses “the idea that management’s own (past) decisions can be incorporated into a system of improving their present decisions” (Bowman, 1961, p. 310). Specifically, he develops production scheduling decision rules which are equations that relate production to sales. They have parameters that can be altered in the form of coefficients. These coefficients can be estimated by regressing management’s past behavior. This begs the question, however are “bad” decisions being incorporated into the model? In *New Theory on Managerial Decision Making*, Kunreuther is referring to this possibility when he points out “the manager may consistently underestimate or overestimate his decision variables thus exhibiting a bias in his behavior” (Kunreuther, 1969, p. 417). Since the response functions used by this thesis are based on past performance, it must be noted that there is a possibility that “bad” decisions could be incorporated in this model.

## **Optimization**

An optimization problem is used to maximize or minimize an objective (or multi-objective) function taking into account a series of constraints placed upon the decision variables. A basic form for an optimization problem is:

$$\begin{array}{ll}\text{Minimize} & f_0(x) \\ \text{Subject to} & f_i(x) \leq b_i \text{ for } i = 1, \dots, m\end{array}$$

Vector  $x = (x_1, \dots, x_n)$  is the optimization variable,  $f_0$  is the objective function that maps vector  $x$  to a single real value, and  $m$  is the number of constraints. Here, a vector is optimal “[...] if it has the smallest objective value among all vectors that satisfy the

constraints [...]” (Boyd & Vandenberghe, 2004, p. 1). This is also referred to as a global optimal solution. Using the VFT notation from this thesis, our optimization problem becomes:

$$\begin{aligned}
&\text{Maximize} && v(x) = \sum_{i=1}^{33} w_i v_i(x_i) \\
&\text{Subject to} && x_1 + x_2 + \dots x_{33} = 1 \\
&&& x_i \geq l_i \text{ for } i = 1, \dots 33 \text{ where } l_i \in [0,1] \\
&&& x_i \leq u_i \text{ for } i = 1, \dots 33 \text{ where } u_i \in [0,1] \\
&&& \text{and } l_i < u_i \text{ for } i = 1, \dots 33
\end{aligned}$$

Vector  $x = (x_1, \dots, x_{33})$  is the preferred allocation of funds to USAID’s lowest-tier objectives and  $v(x)$  is the additive value function. The first constraint enforces the requirement that allocations sum to one. The remaining constraints limit the allocations to falling between a lower bound ( $l_i$ ) and an upper bound ( $u_i$ ). The reason for a lower and upper bound was to reduce error due to extrapolation when using response functions. The bounds were determined by adding and subtracting 10% of the range of allocations from past performance data to the maximum ( $u_i = x_i + 0.1x_i$ ) and minimum ( $l_i = x_i - 0.1x_i$ ) allocations respectively.

There are two basic classifications for an optimal solution. A global optimal solution is a maximum or minimum when compared to all possible solutions that satisfy the constraints. A local optimal solution is a maximum or minimum when compared to a neighboring set of solutions. For the purposes of this thesis, due to non-smooth nature of the surface we will consider a heuristic solution. This solution is simply an improvement to the objective function due to optimization but it cannot be said that it is a global or even a local optimum.

The methodology used to solve an optimization depends upon the model's characteristics. Continuous optimization problems can be broken down into two types: linear and nonlinear. In general, a linear problem is easier to solve (less complex) than a nonlinear. A linear optimization involves an objective function and constraints that are linear. The Simplex Method could be used to solve a linear constrained optimization. A nonlinear optimization could involve higher order polynomials, exponentials, and logarithmic functions. Such methods as Generalized Reduced Gradient and Sequential Quadratic Programming can be used to solve an appropriate nonlinear optimization. Continuous nonlinear optimization problems can be further broken down into two types: smooth and non-smooth. Non-smooth involves functions that have "kinks" or are discontinuous. In general, a smooth problem is easier to solve than a non-smooth problem. An evolutionary algorithm can be used to seek an improved solution to a non-smooth optimization (Frontline Solvers User Guide, 2011). Since the objective function used in this thesis is nonlinear non-smooth, an evolutionary algorithm was chosen to solve the optimization via Excel 2010 Premium Solver Platform V11.5.

Part of the reason a non-smooth problem (NSP) is difficult to solve is because its function (or functions) is not differentiable throughout its domain. This means that derivatives or gradients cannot be used to determine conclusively which direction a function is improving without restricting the domain. Because the Evolutionary Solver has no way to test if a solution is optimal, it relies on either a heuristic rule, chosen length of time, or chosen number of iterations to stop the calculation. This means the heuristic is not guaranteed to produce a global or local optimal solution (although it is possible). It is expected to produce an improved solution. From the *Frontline Solvers User Guide*, an

evolutionary algorithm differs from “classical” algorithms in the following ways

(Frontline Solvers User Guide, 2011, p. 205):

1. “[...] it relies in part on random sampling.”
2. “[...] where most classical optimization methods maintain a single best solution found so far, an evolutionary algorithm maintains a population of candidate solutions.”
3. “[...] periodically makes random changes or mutations in one or more members of the current population, yielding a new candidate solution.”
4. “[...] attempts to combine elements of existing solutions in order to create a new solution [...]”
5. “[...] performs a selection process in which the ‘most fit’ members of the population survive, and the ‘least fit’ members are eliminated.”

The first difference tells us that the heuristic is nondeterministic. This means executing the procedure twice from the same starting point can yield a different solution. The second difference helps avoid being “trapped” at a local optimal solution. The remaining differences are a way of improving the candidate population from which the “best” solution is chosen. For this thesis, the stopping condition used was a convergence of  $10^{-6}$ . This will stop the evolutionary engine when five consecutive iterations produce objective function values that are within  $10^{-6}$  of one another.

This section overviewed some basic concepts of VFT, regression, and optimization along with briefly mentioning how they are used in this thesis. The methodology section shows how these tools are integrated to form a prototype overview



that can be used to indicate how changing allocations can improve impact based on the stated values of USAID.

### **III. Methodology**

#### **Overview**

This thesis provides a prototype overview that takes strategic level objectives of USAID and transforms them into a mathematical model that can be applied to any region or nation that is receiving foreign aid. This model is intended to support spending allocation recommendations to USAID DMs. Specifically, an additive value function is generated based on Value Focus Thinking (VFT) methodology turning USAID's Seven Core Development Objectives into measurable quantities from which alternative allocations can be evaluated. Since there are an infinite number of possible allocations, an optimization was conducted to demonstrate maximizing (or at least improving) the value function by varying allocations to USAID's Seven Core Development Objectives.

#### **Fundamental Objective**

In Keeney's book *Value-Focus Thinking* he identifies an overall fundamental objective as the "[...] reason for interest in the decision situation and defines the breadth of concern" (Keeney, 1992, p. 77). In other words, it is the all-encompassing problem that is being addressed by the VFT model. On the USAID official website the agency states that its purpose is in "[...] furthering America's interests while improving lives in the developing world" and that it "[...] has been the principal U.S. agency to extend assistance to countries recovering from disaster, trying to escape poverty, and engaging in democratic reforms" (USAID: From the American People, 2012). Basically, the agency is trying to improve lives globally while adhering to United States foreign policy as articulated by the Department of State. The fundamental objective is how best to allocate

funding to support USAID's stated values given in the form of the Seven Core Development Objectives.

### **Value Hierarchy**

The next step in our process is to take USAID's values as stated in the Seven Core Development Objectives and create a Value Hierarchy to give some structure to the decision situation. USAID's Seven Core Development Objectives are (USAID Policy Framework 2011-2015, 2011):

1. Increase Food Security: Rekindling the Power of Transformational Agriculture
2. Promote Global Health and Strong Health Systems: From Treating Diseases to Treating People
3. Reduce Climate Change Impacts and Promote Low Emissions Growth: Building Resilience on Multiple Fronts
4. Promote Sustainable, Broad-Based Economic Growth: Enable the Private Sector to Drive Growth
5. Expand and Sustain the Ranks of Stable, Prosperous, and Democratic States: Supporting the Next Generation of Democratic Transitions
6. Provide Humanitarian Assistance and Support Disaster Mitigation: Building Resilience and Preparedness
7. Prevent and Respond to Crises, Conflict, and Instability: Applying Development Approaches in Fragile and Conflict-Affected States

A necessity for any value hierarchy is that its elements (objectives and measures) be mutually exclusive and collectively exhaustive. Although the Seven Core Development Objectives have a great deal of overlap, they are formulated to be mutually

exclusive for the purposes of this model. In addition, the values expressed therein are assumed to encompass all the values pertinent to this decision situation and are therefore collectively exhaustive.

Two common approaches to creating a value hierarchy are a bottom-up and top-down approach. The former refers to starting with basic objectives or measures that create value for the DM and grouping them in such a way that higher level objectives can be defined that are mutually exclusive and collectively exhaustive. The latter refers to starting with strategic level objectives and defining sub-objectives until they cannot be further sub-divided. For this thesis, a hybrid of the two approaches was used. The Seven Core Development Objectives were taken as the first or highest tier placed directly below the fundamental objective in the hierarchy. Underneath each of these seven objectives a bottom-up approach was used. From USAID Policy, sub-objectives were identified and grouped into mutually exclusive objectives (affinity diagram) creating additional tiers (USAID Policy Framework 2011-2015, 2011). For each basic item that created value (lowest tier), a suitable measure was identified for which data could be collected. Figure 3 shows the first-tier objectives displayed vertically. Figures 4 thru 10 show the sub-hierarchies falling beneath each of the seven first-tier objectives. These sub-hierarchies combine to form a single hierarchy under the fundamental objective (see Appendices A and B for full hierarchies with global and local weights respectively).

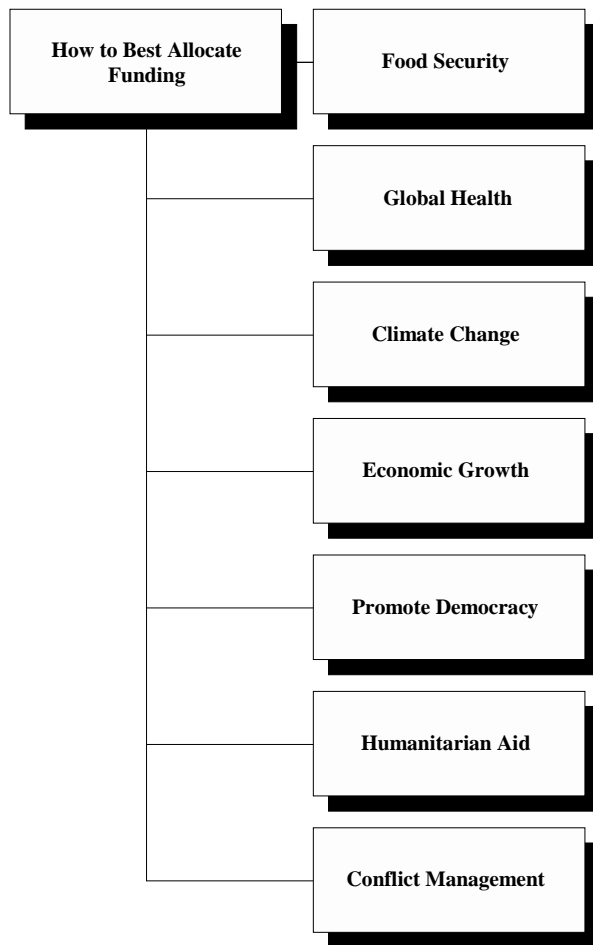


Figure 3. First Tier of Value Hierarchy

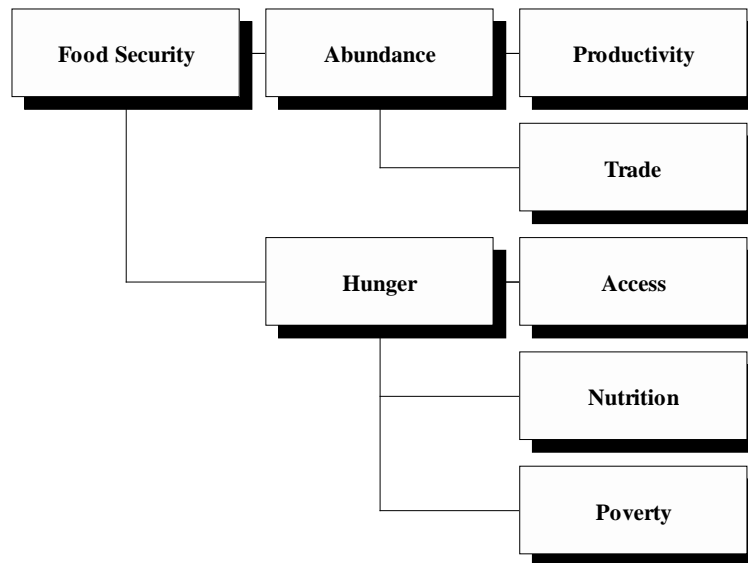


Figure 4. Food Security Sub-Hierarchy

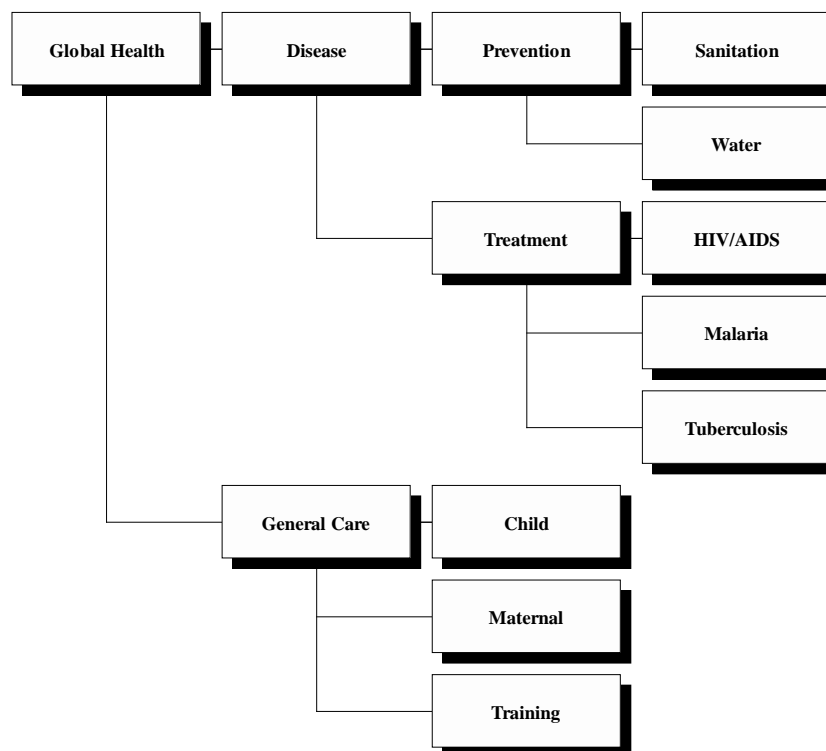


Figure 5. Global Health Sub-Hierarchy

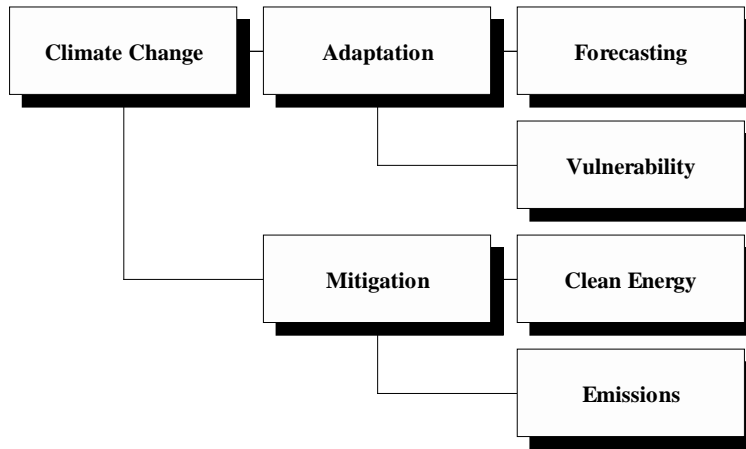


Figure 6. Climate Change Sub-Hierarchy

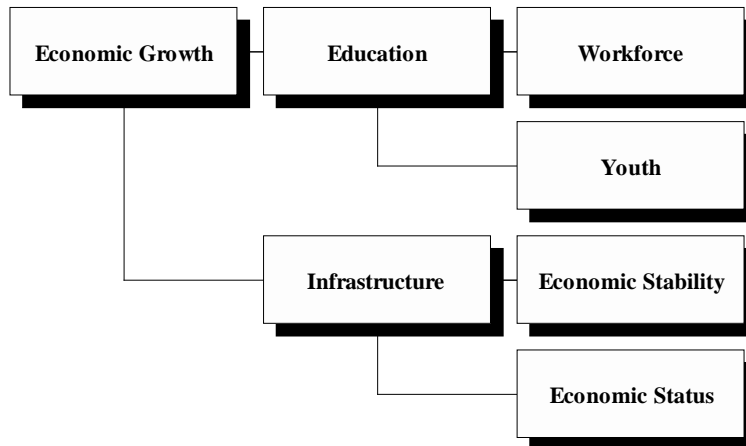


Figure 7. Economic Growth Sub-Hierarchy

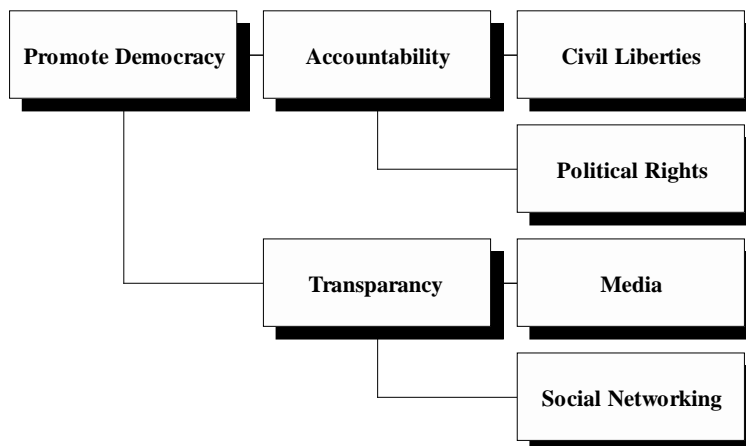


Figure 8. Promote Democracy Sub-Hierarchy

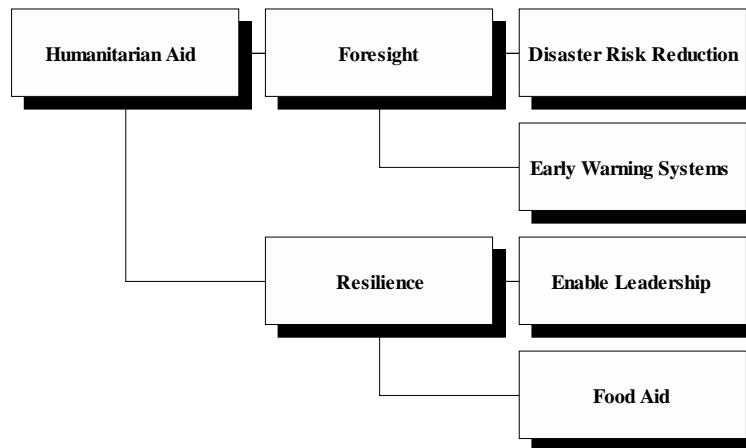


Figure 9. Humanitarian Aid Sub-Hierarchy

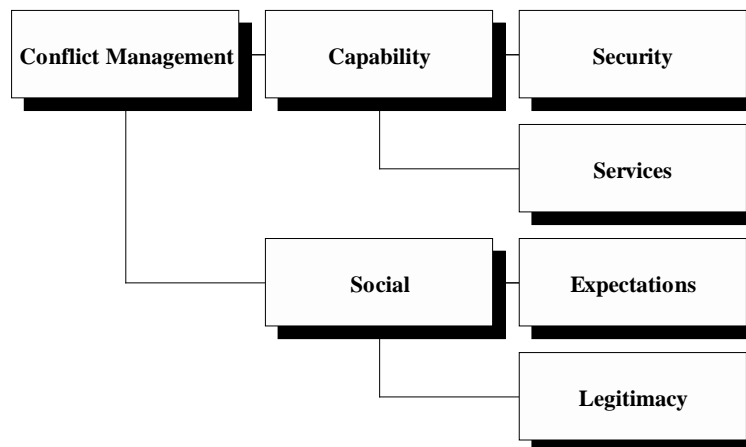


Figure 10. Conflict Management Sub-Hierarchy

Data for the measures was attained from World Bank (WB) and Freedom House (FH) databases (The World Bank, 2012) (Reports: Freedom House). The measures corresponding to the lowest tier objectives are:

- Food Security - Abundance
  1. Productivity – Agricultural GDP per capita (WB)
  2. Trade - Country Policy and Institutional Assessment (CPIA) trade rating (WB)
- Food Security - Hunger



3. Access – Total network of roads in kilometers (WB)
4. Nutrition - Percentage of population undernourished (WB)
5. Poverty – Percentage of population living on less than \$1.25 a day (WB)
- Global health - Disease prevention
  6. Sanitation - Percentage of population with access to improved sanitation (WB)
  7. Water - Percentage of population with access to improved water source (WB)
- Global health - Disease treatment
  8. HIV/AIDS - Percentage of people with HIV/AIDS receiving treatment (WB)
  9. Malaria - Percentage of children with fever receiving antimalarial drugs (WB)
  10. Tuberculosis - Percentage tuberculosis treatment success of registered cases (WB)
- Global health - General care
  11. Child - Under 5 mortality rate per 1000 (WB)
  12. Maternal - Maternal mortality rate per 100,000 live births (WB)
  13. Training - Number of physicians per 1000 people (WB)
- Climate change - Adaptation
  14. Forecasting - Number of observation hubs utilized
  15. Vulnerability - CPIA environmental sustainability rating (WB)
- Climate change - Mitigation
  16. Clean energy - Percentage alternative and nuclear energy of total energy use (WB)
  17. Emissions - CO2 emissions in metric tons per capita (WB)
- Economic growth - Education

- 18. Workforce - Percentage of total labor force unemployed (WB)
- 19. Youth - Percentage of children enrolled in primary school (WB)
- Economic growth - Infrastructure
- 20. Economic stability - Percentage of GDP cash surplus/deficit (WB)
- 21. Economic status - Gross domestic product per capita (WB)
- Promote democracy - Accountability
- 22. Civil liberties - Civil liberties index (FH)
- 23. Political rights - Political rights index (FH)
- Promote democracy - Transparency
- 24. Media - Freedom of the press rating (FH)
- 25. Social networking - Internet users per 100 people (WB)
- Humanitarian aid - Foresight
- 26. Disaster risk reduction - Disaster risk reduction progress score (WB)
- 27. Early warning systems - Number of early warning systems accessible
- Humanitarian aid - Resilience
- 28. Enable leadership - CPIA public sector management and institutions average (WB)
- 29. Food aid - Depth of hunger in kilocalories per person per day (WB)
- Conflict management - Capability
- 30. Security - Intentional homicides per 100,000 people (WB)
- 31. Services - CPIA quality of public administration rating (WB)
- Conflict management - Social
- 32. Expectations - CPIA social protection rating (WB)

### 33. Legitimacy - CPIA policies for social inclusion/equity cluster average (WB)

A definition of the measures can be found in Appendix C. As discussed in the literature review section, a natural direct measure is preferable when quantifying values. For this model, most values were quantified using proxy measures.

#### Value Function

Although the use of a multiplicative value function was considered, it was decided, for the sake of clarity in this first-cut overview, that an additive function would be sufficient. In addition, an additive function was chosen because the assumption of mutual preferential independence was reasonable to make. This thesis defines the value function as:

$$v(x) = \sum_{i=1}^{33} w_i v_i(x_i)$$
$$\text{where } \sum_{i=1}^{33} w_i = 1, v_i(x_i) \in [0,1]$$

Here  $w_i$  are the global weights,  $v_i$  are single dimensional value functions (SDVF), and  $x_i$  are measure quantities. For the measures that are continuous, a SDVF was used of the form:

$$v_i(x_i) = \begin{cases} \frac{1 - e^{-(x_i - x_i^L)/\rho_i}}{1 - e^{-(x_i^H - x_i^L)/\rho_i}} & \text{for } \rho_i \neq \infty \\ \frac{x_i - x_i^L}{x_i^H - x_i^L} & \text{otherwise} \end{cases} \quad \text{where } i = 1, \dots, 33$$

Here  $v_i$  are SDVFs,  $x_i$  are measure quantities,  $x_i^L$  are least preferred measure quantities,  $x_i^H$  are most preferred measure quantities, and  $\rho_i$  are exponential constants

(Kirkwood, 1997, p. 65). The exponential constant determines if a SDVF has increasing or decreasing returns to scale. It also determines how far from linear the SDVF is. As the magnitude of  $\rho_i$  increases the SDVF approaches linearity. There is no closed form solution to solve for  $\rho_i$ , so it is solved numerically. For this model's exponential and S-curve SDVFs, equations were taken from Weir's Hierarchy Builder (Weir, 2008) and used in the Excel spreadsheet optimization. For measures that are categorical, value increments were assumed to be equal.

### **Optimization Approach**

The VFT process is ideally suited for comparing a discrete set of alternatives. Since this thesis is addressing a continuous set of alternatives (funding allocation), additional methodology is required. In his book *Strategic Decision Making*, Kirkwood discusses the concept of using an Excel Data Table to optimize a funding allocation in order to maximize value based on the value function (Kirkwood, 1997, pp. 85-96). A similar process is utilized herein to consider potential desired allocations. It is important to note that it is assumed there is no uncertainty. Another assumption being made is that changing budget allocations changes measure quantities "smoothly" (Kirkwood, 1997).

The first step in this process was to form response functions by finding, for each measure, several quantities corresponding to different allocations of funding. Allocations to values within the hierarchy were desired that were as close as possible to the corresponding measure. For example, when tying the productivity measure (Agriculture, value added in current US\$) to an allocation it was preferable to use an allocation to the third-tier value (Productivity) versus using an allocation to the first-tier value (Food Security). It was assumed that the closer one was to the other, the stronger the correlation

between the two. Since USAID policy is undergoing a period of transition, past allocations were organized under different headings (Congressional Budget Justification: Foreign Operations) than that found in the new framework (USAID Policy Framework 2011-2015, 2011). This meant that allocations could typically be found for second-tier values but allocations to the lowest tier values were hard to come by. Once the lowest possible allocations were found, they were divided equally among their sub-values.

Table 4 shows the data used to form the Productivity measure response function:

	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>	<b>2010</b>
Allocation	0.065815	0.056114	0.019877	0.018473	0.002468	0.010099	0.016347
Measure	840.36	946.90	867.42	935.49	1040.42	872.25	851.99

Table 4. Data Points for Productivity Measure Response Function

From here, regression was utilized to find a smooth curve (response function) that approximates the given data points (see Figure 11 with confidence interval at  $\alpha = 0.05$ ). Thereafter, this response function was used to calculate a measure quantity when varying budget allocations in the optimization. Using the SDVF, the measure quantities were translated into measure values between zero and one. Using the additive value function, these individual measure values were scaled by weights and rolled up into a single score to be maximized when optimizing (see Figure 12). Within the optimization, the vertical axis of the response function becomes the horizontal access of the SDVF.

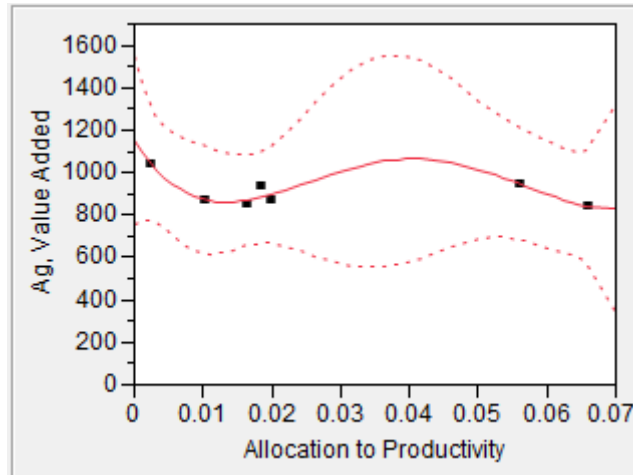


Figure 11. Productivity Measure Response Function



Figure 12. Process Flow Chart

This section has shown how these tools were integrated to form a mathematical model that can be used to indicate how changing allocations can improve impact based on the stated values of USAID. The results and analysis section shows how this was applied to a specific nation with a demonstration model.

## **IV. Results and Analysis**

### **Georgia**

The USAID structure and availability of data were driving factors when choosing a location for this demonstration model. USAID has overseas “missions” assigned to specific countries that are grouped into regions. Each of these missions has their own set of objectives that express their values in terms of meeting the needs of the country’s populace while adhering to the overall objectives of USAID and United States foreign policy. Typically, the mission’s objectives are a subset or a slightly altered version of USAID’s Seven Core Development Objectives.

For this demonstration model, an abundance of data was needed. This data set had to quantify as many of the 33 measures as possible so that the additive value function could be used to demonstrate the impact of varying allocations in funding. This data would be used to develop SDVFs as well as response functions for the model. The World Bank Group (WBG) is comprised of five international organizations that make leveraged loans to developing countries. Traditionally, its president is nominated by the United States President since the US is the largest shareholder. Within the WBG, the Independent Evaluation Group collects data at the nation-state level that is used to assess the impact of WBG globally. This data has been made available to the public and was used to quantify most of the 33 measures in this thesis (The World Bank, 2012). For some of the measures relating to promoting democracy, data attained from Freedom House was used. Freedom House is a US-based non-governmental organization that conducts research and advocacy on democracy, political freedom, and human rights (About Us: Freedom House).

Given the USAID mission structure and nature of WBG data, it was decided to apply the model at the nation-state level. Next, a specific nation was chosen that is a recipient of foreign aid via USAID and data could be found from WBG that would quantify the measures to demonstrate the approach. Based on these two criteria, the nation of Georgia was chosen. For FY 2009 and 2010, Georgia was ranked ten and eleven respectively among countries receiving the most aid from USAID. For four of the suggested measures from the methodology section, a similar measure was used because no data was found for the suggested measure. For five of the suggested measures, no data was found that would quantify the corresponding value of USAID. The nine values that are being measured are shown in Table 5 along with the new measure, where applicable. See Appendix C for a definition of all measures used in this demonstration model.

<u>Measure</u>	<u>Value</u>	<u>Data Used</u>
	<b>Food Security</b>	
1	Abundance - Productivity	Agriculture, value added (current US\$)
4	Hunger - Nutrition	No data
5	Hunger - Poverty	Poverty headcount ratio at \$1.25 a day (% of population)
	<b>Global Health</b>	
8	Disease treatment - HIV/AIDS	Prevalence of HIV, total (% of population ages 15-49)
9	Disease treatment - Malaria	Reported cases of Malaria
13	General Care - Training	No data
	<b>Climate Change</b>	
14	Adaptation - Forecasting	No data
	<b>Humanitarian Aid</b>	
26	Foresight - Risk Reduction	No data
27	Foresight - Warning Systems	No data

Table 5. Measures Specific to Georgia Demonstration



## Response Functions

Documentation and past data were used to develop response functions, value weights, and SDVFs for this demonstration model. Response functions were used to estimate measure quantities when varying funding allocations in the optimization. Here, a single data point consisted of a measure quantity and the allocation to its parent value. Taking as many data points as available, regression was performed to come up with a polynomial that could estimate a measure quantity for a given funding allocation. These polynomials were then used when optimizing. Figures 13, 14, and 15 show some regression plots from JMP with confidence intervals at  $\alpha = 0.05$ . Table 6 shows the parameters used for model selection. For these three examples,  $C_p$  was looked at first where it approached  $p$  (lower is better). Then  $R^2$  and adjusted  $R^2$  were looked at to make a final selection (higher is better).

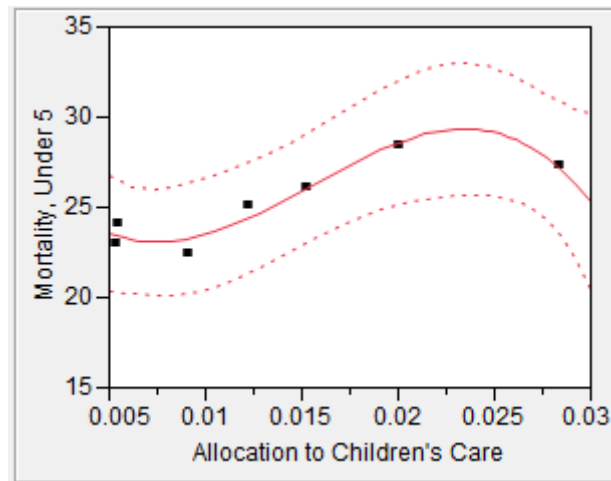


Figure 13. Measure 11 (Mortality, Under 5 per 1000) Regression

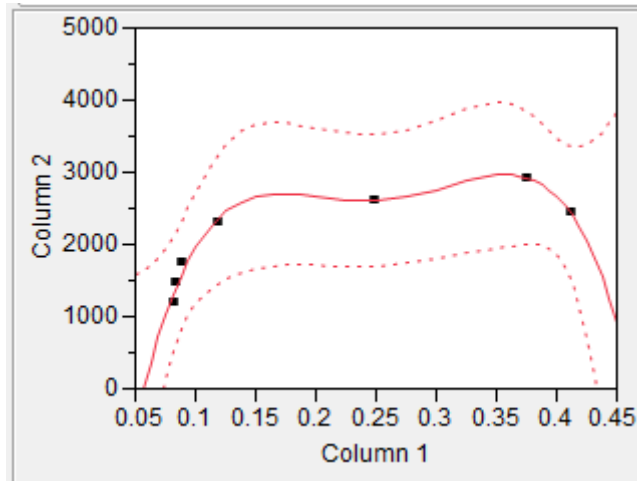


Figure 14. Measure 21 (Gross Domestic Product Per Capita) Regression

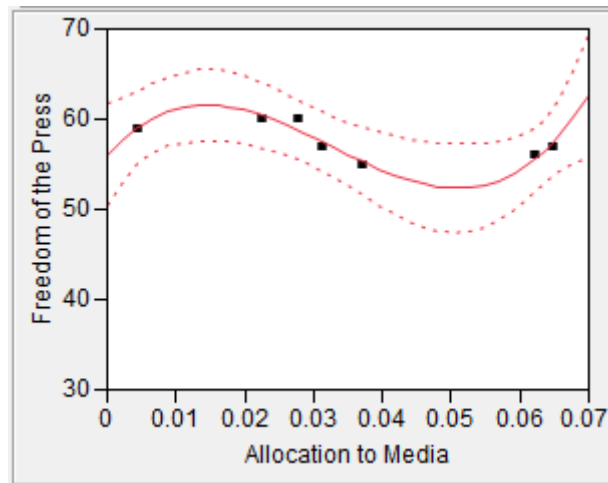


Figure 15. Measure 24 (Freedom of the Press Rating) Regression

Measure	R-squared	Adj. R-squared	p	Cp
11	0.8794	0.8191	3	4.1177
21	0.9748	0.9622	2	1.7064
24	0.8941	0.7882	3	3.12

Table 6. Regression Model Selection Parameters

This method of determining response functions points out some interesting results. A greater allocation to a value does not necessarily result in a higher preference

quantity for its corresponding measure. In addition, past allocations varied a great deal for some values while very little for others. The allocation to Economic Growth varied between 0.2 and 0.83 (width of range of 0.63) while the allocation to Climate Change varied between 0.0 and 0.02 (width of range of 0.02) over the years 2004 thru 2011. The smaller the range of allocations, the more likely that extrapolation (versus interpolation) is necessary when making use of the response function in the optimization. To counteract this, constraints are used in the optimization to ensure allocations are close to past data. Ten percent of the range of allocations is subtracted from the minimum allocation and added to the maximum allocation to form a lower and upper bound respectively. For instance, the demonstration model will not consider less than a 0.049 or greater than a 0.444 allocation to Economic Stability.

## **Weights**

From the *Congressional Budget Justification Foreign Operations Annex: Regional Perspectives* for FY 2012, the foreign assistance program overview for Georgia gives a breakdown of its funding request that was used to find dollar amounts being requested to support the values of this demonstration model. From this request, proportions were calculated (dollar amount requested to support a first-tier objective divided by the total amount requested) and used as first-tier weights. The breakdown includes money requested by program area. In some instances, the program areas were descriptive enough to be grouped into second-tier values and thereby used to calculate second-tier weights. In this manner, second-tier weights were calculated that fell beneath first-tier objectives Economic Growth, Promote Democracy, and Conflict Management. Elsewhere in the hierarchy, weights were simply divided equally amongst the lower tiers.

For example, the first-tier objective Food Security weight of 0.075 was divided equally among its 5 measures while the first-tier objective Economic Growth weight of 0.247 had 0.093 going to the second-tier objective Education and 0.907 going to the second-tier objective Infrastructure. Weights were developed on the hierarchy top-down until no more value information could be derived from the funding request at which point objectives and measures were weighed equally. Using this weighing methodology resulted in a weight of no more than 0.011 for any of the five measures for which data could not be found. The total weight for all five missing measures is approximately 0.05.

### **Single Dimension Value Functions**

The SDVFs were formed by reviewing past data, as well as reviewing goals that USAID was trying to reach with respect to the measures. For each measure, the most recent measure quantity was found and taken as the least preferred quantity. The reasoning behind this is that a great deal of the documentation regarding what USAID is trying to accomplish states that a positive impact is desired. If any positive impact generates value, then it is reasonable to assume that no or negative impact generates no value. Thus if a measure quantity remains the same or depreciates then zero value is added to the additive value function.

To give shape to the SDVFs, goals were reviewed. Goals were found in USAID Policy that can also be seen in the policy from such organizations as Millennium Development Goals (MDG), Global Health Initiative (GHI), and Feed the Future Initiative (FtF) (USAID Policy Framework 2011-2015, 2011). For this demonstration model, it is assumed that all nine categorical measures increment in value linearly. Of

the remaining nineteen continuous measures, twelve are linear and seven are nonlinear. Of the seven nonlinear, two are *S*-curve and five are exponential.

Weir's Hierarchy Builder (Weir, 2008) was used to find value equations for the nonlinear SDVFs. For the *S*-curve SDVFs, two exponential equations (for each SDVF) were used as an approximation. SDVFs were defined as linear when nothing could be found in USAID policy, underlying documentation (MDG, GHI, and FtF policy), or common practice to indicate they should be otherwise. In addition, they were defined as linear if the range between least preferred and most preferred quantity was seen as negligibly small. That is to say, the percentage change from least to most preferred quantity was approximately 10% or less. SDVFs were defined as nonlinear for a variety of reasons. For several of the measures, USAID had short term goals (annual targets) as well as long term goals (MDG). For this case, the short term goal was defined as an 80% solution giving the SDVF a decreasing return-to-scale. For some percentage measures, if a goal was close to 100% it was assumed that as a quantity increased it would increment less in value as the goal was approached thereby indicating a decreasing return-to-scale. Only two of the measures had both an increasing and a decreasing return-to-scale (*S*-curve). For these measures, value increment was minimal until a threshold was reached, at which point value incremented dramatically until a goal was reached and the increment became minimal again.

### **Optimization Demonstration**

The next step was to optimize to find an allocation of funding that would improve the value function score by using the response functions, weights, and SDVFs. The

weights and SDVFs were combined to form the following additive value function to be maximized with allocation bounds given in Table 7 and global weights given in Table 8:

$$\begin{aligned} \text{Maximize} \quad & v(x) = \sum_{i=1}^{33} w_i v_i(x_i) \\ \text{Subject to} \quad & x_1 + x_2 + \dots + x_{33} = 1 \\ & x_i \geq l_i \text{ for } i = 1, \dots, 33 \\ & x_i \leq u_i \text{ for } i = 1, \dots, 33 \end{aligned}$$

i	Lower	Upper	i	Lower	Upper	i	Lower	Upper
1	0	0.07215	12	0.003094	0.030615	24	0	0.070782
2	0	0.061478	15	0	0.001282	25	0	0.070782
3	0.009159	0.047033	16	0	0.001282	28	0	0.021823
5	0	0.040986	17	0	0.001282	29	0	0.021823
6	0.003445	0.010596	18	0	0.12085	30	0	0.115357
7	0.00239	0.004543	19	0	0.12085	31	0	0.115655
8	0.001077	0.020019	20	0.048658	0.444271	32	0	0.157119
9	0.001157	0.006519	21	0.048658	0.444271	33	0	0.157119
10	0.000582	0.014149	22	0	0.072048			
11	0.00301	0.030623	23	0	0.072048			

Table 7. Allocation Bounds for Georgia Demonstration

Measure	Weight	Measure	Weight
1 and 2	0.0187	20 and 21	0.1120
3	0	22 and 23	0.1115
4 and 5	0.0187	24 and 25	0.0283
6 thru 12	0.0086	26 and 27	0
13 and 14	0	28 and 29	0.0126
15 thru 17	0.0095	30 and 31	0.1391
18 and 19	0.0115	32 and 33	0.0032

Table 8. Global Weights for Georgia Demonstration

As mentioned earlier, no data could be found for five measures. These measures were effectively removed from the model by giving them a weight of zero.

For this thesis, most calculation was completed with the use of Excel 2010. A spreadsheet was created that would use Excel 2010 Premium Solver Platform V11.5 to maximize the value function by varying allocations to the lowest-tier values. Using the response functions, measure quantities were calculated for the varying allocations. Using the SDVFs, measure quantities were converted to unit-less values. Using weights, the unit-less values were combined via the additive value function into a single value that was maximized. For this demonstration model, the additive value function sums 28 terms corresponding to measures for which data could be found. Here is an example of the calculation involved in determining a single term (measure 1) beginning with converting the Productivity allocation (decision variable denoted by  $x_1$ ) to a measure quantity using the response function corresponding to measure 1 (denoted by  $f_1$ ):

$$f_1(x_1) = 205843129(x_1 - 0.02703)^4 - 15140349(x_1 - 0.02703)^3 + 8192.926x_1 + 717.1874$$

Next, the measure quantity is converted to a unit-less value using the SDVF corresponding to measure 1 (denoted by  $v_1$ ):

$$v_1[f_1(x_1)] = \begin{cases} 0, & \text{for } f_1(x_1) < 850 \\ 1 - e^{\frac{-(f_1(x_1) - 850)}{155.4631}}, & \text{for } 850 \leq f_1(x_1) \leq 1150 \\ 1, & \text{for } f_1(x_1) > 1150 \end{cases}$$

It is important to note that this last step is the reason the overall value function is non-smooth (it introduces kinks). From here, this value is scaled by the global weight corresponding to measure 1. This forms the first of 28 terms which will be summed and then maximized:

$$v(x) = 0.0172v_1[f_1(x_1)] + \dots \text{ where } x = (x_1, x_2, \dots, x_{33})$$

From just this first term we can see that  $v(x)$  is a nonlinear non-smooth function. Table 9 shows some calculation for measures falling beneath the Economic Growth and Promote Democracy values (weights are global):

Measure	Quantity	SDVF	Weight	SDVF*W
18	12.0336	0.7836	0.0115	0.0090
19	101.22	1	0.0115	0.0115
20	1.0220	1	0.1120	0.1120
21	3023.29	0.8842	0.1120	0.0991
22	3.4353	0	0.1115	0
23	3.3967	0.2011	0.1115	0.0224
24	61.5849	0.8231	0.0283	0.0233
25	24.1165	0	0.0283	0

Table 9. Spreadsheet Calculation

The far right column was summed over all 28 measures and this single value was maximized in the optimization. Since the resulting value function was nonlinear non-smooth, the solving method used in Excel was evolutionary. The convergence stopping condition was lowered from the default ( $10^{-6}$  to  $10^{-9}$ ) so that consecutive runs from the same starting allocation would give results that were almost equal to one another. Using the evolutionary method gave an improved solution. Varying the starting allocation resulted in improved solutions that fell in between 0.4703 and 0.4829. Since the value function is non-smooth, optimality could not be verified. Historical allocations for 2004 thru 2011 were used as starting allocations. Table 10 shows the resulting improved solutions:



First-Tier Value	Allocations							
	2004		2005		2006		2007	
	Start	Finish	Start	Finish	Start	Finish	Start	Finish
1	0.2633	0.0092	0.2245	0.0092	0.0795	0.0092	0.0739	<b>0.0092</b>
2	0.0624	0.0148	0.0965	0.0148	0.0894	0.0148	0.0729	<b>0.024</b>
3	0	0.0016	0	0	0.0047	0	0	<b>0</b>
4	0.3601	0.4673	0.3882	0.4003	0.2003	0.3862	0.2697	<b>0.4359</b>
5	0.2515	0.1042	0.2613	0.1698	0.1008	0.1428	0.1131	<b>0.0981</b>
6	0	0.0218	0	0.0003	0.0397	0	0.0245	<b>0.0295</b>
7	0.0627	0.3812	0.0295	0.4057	0.4856	0.4471	0.446	<b>0.4032</b>
Value Function Results								
	0.301	0.4815	0.2141	0.4753	0.2915	0.4703	0.2364	<b>0.4829</b>
	59.96% increase		121.96% increase		61.32% increase		104.3% increase	

First-Tier Value	Allocations							
	2008		2009		2010		2011	
	Start	Finish	Start	Finish	Start	Finish	Start	Finish
1	0.0099	0.0092	0.0404	0.0558	0.0654	0.0092	0.1001	0.0092
2	0.0323	0.0148	0.0319	0.0235	0.0542	0.0148	0.1053	0.0148
3	0.0002	0	0.0027	0.0002	0.0026	0	0.0207	0
4	0.7575	0.4003	0.8302	0.4693	0.5366	0.545	0.4235	0.4003
5	0.0808	0.1994	0.0174	0.1553	0.1276	0.1577	0.1742	0.2149
6	0.0214	0.0112	0.0611	0.0189	0.1605	0.0218	0	0.0199
7	0.0979	0.3652	0.0163	0.2769	0.053	0.2516	0.1762	0.3411
Value Function Results								
	0.4062	0.4753	0.0732	0.4763	0.2946	0.4798	0.2095	0.4753
	17.01% increase		550.89% increase		62.88% increase		126.86% increase	

Table 10. Optimization Results

Table 10 shows that the optimization process improved the overall value by as little as 17.01 percent and by as much as 550.89 percent when compared to past allocations. The maximum value function score found and its corresponding allocation are highlighted. For the Georgia demonstration, this is our best alternative. Various other starting allocations were tried. The highest value score seen was near 0.48. Of

note, Climate Change hovered around zero due to constraints based on historical allocations. Conflict Management increased by as little as a factor of 0.9 and as much as a factor of 16.97. Comparatively, large deltas were seen for this allocation. It is again noted, however, that these are demonstration values and should be treated as such.

A topic that has not been considered is how the value function score changes in relation to changes in the overall funding level of the organization. Rather than express this as a dollar amounts, proportional changes to the overall funding level were looked at. Using the best alternative as a starting allocation, the default funding level (1.0) was incremented ( $\pm 0.2$ ) and a value function score was calculated. Since the decision variable constraints restricted the overall funding level to be less than approximately 2.35, levels were not used beyond this value. Figure 15 shows how the value function score responded to changes in overall funding levels.

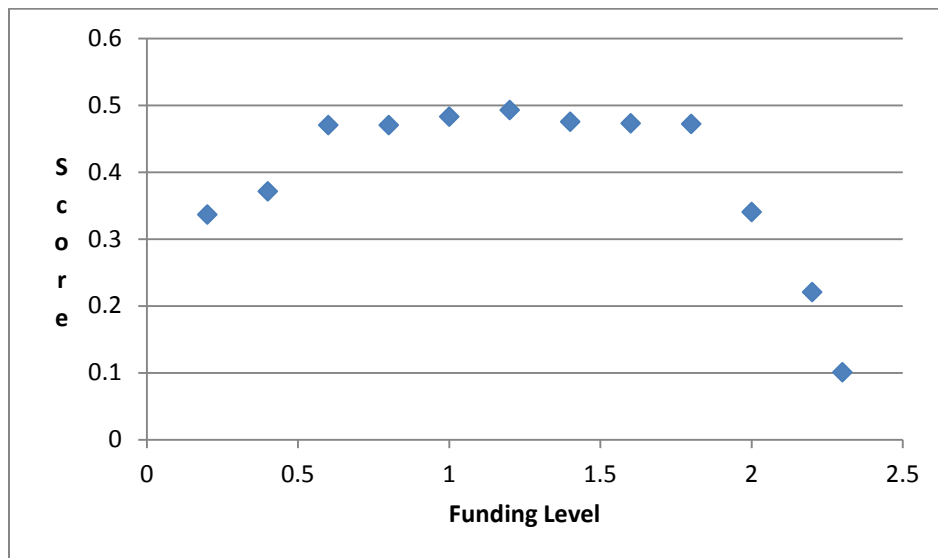


Figure 16. Effect of Funding Level on Value Score

Intuitively, having a larger amount of funds to work with should result in a higher value function output. This is reflected in the score increase seen for funding levels at 0.6 and below. However, for funding levels at 1.8 and above, the score decreases. The reason for this may be because the response functions are not monotonic and many of them experience a decrease in value on the high end of the decision variable constraint. For the Economic Status measure (GDP per capita), the optimization constraint forces its allocation to be between approximately 0.05 and 0.44. From 0.37 to 0.44, the response function decreases in value. For the funding levels of 1.8 and above, allocation is being forced into response functions that decrease the value function score. Another take-away from Figure 15 is that, in between funding levels of 0.6 and 1.8, very little change is seen in score indicating a possible saturation level to funding.

This thesis has posed a problem to be addressed, mentioned previous research conducted, discussed the background behind tools that were used, integrated those tools in a unique way, and applied the methodology to Georgia. Now comes concluding remarks regarding the prototype overview introduced by this thesis.

## **V. Conclusions**

USAID is an agency with global reach responsible for administering the bulk of United States foreign aid abroad (over \$15 billion FY 2011). The purpose of this thesis was to provide a prototype overview methodology that could be applied to a region or nation by a USAID DM to better understand the decision context. Values were derived from USAID policy and underlying documentation. Underlying documentation came from the policy of agencies and initiatives that USAID directly supports. Some examples are Millennium Development Goals, Global Health Initiative, Feed the Future Initiative, Global Climate Change Initiative, and President's Partnership for Growth. The methodology demonstrated in this thesis shows how USAID policy and supporting documentation can be combined to form a value model. This demonstration model shows how varying a given allocation can positively impact the quality of the outcome for a decision. The model can be used to point to a cause of an allocation score (traceable). The model can be applied to any given starting allocation (repeatable). The model can be used to rationalize a choice of allocation (defensible). The prototype overview introduced by this thesis can be used in conjunction with DM and SME (stakeholder) interaction. This interaction can further validate and improve upon the model's accuracy in reflecting the values of the organization. USAID policy is currently in a period of transition to the new framework (USAID Policy Framework 2011-2015, 2011). Given this, interaction with a stakeholder will be particularly useful in clarifying what USAID values at the region and nation mission levels. In addition, the application

of this model might yield more fruit if applied after this period of transition when low and high echelon policy is more closely aligned.

Using polynomial regression (data mining), response functions were formed by looking at measure quantities for various allocations (performance data). As more data becomes available as a result of technological advances and growth of the global community, response functions will better reflect how varying allocations effect performance. In addition, economists could be used to develop tighter response functions. As a future study, performance data can be compared amongst regions and nations (or even globally) to get a more complete picture of how one affects the other. Another study could look at interactions between the decision variables (response surface versus response function). As mentioned, this process can be used in conjunction with DM and SME input.

This thesis took the methodology introduced by Kirkwood for solving a VFT problem with continuous decision variables and expanded upon it (Kirkwood, 1997). Kirkwood used a quadratic equation fitted to three elicited data points for response functions. For these data points, allocations were tied to measure quantities one tier below in the value hierarchy. This thesis used polynomial regression on performance data for its response functions. Allocations were at times two and three tiers removed from the corresponding measure quantity so allocations at the lowest tier had to be calculated. The reason for this was because an assumption was made that the closer an allocation was to a measure, the more useful it would be when determining response functions. An allocation to the first-tier objective Promote Democracy might be loosely related to the internet users per 100 people measure. However, an allocation to the third-

tier objective social networking might give a more accurate idea of how an allocation affects this measure quantity. Kirkwood used an Excel data table to maximize the value function. This thesis used an evolutionary algorithm via Excel 2010 Premium Solver Platform V11.5 for its optimization. Hopefully, this thesis has provided a first-cut methodology on how a value model can be developed for a global agency with the size and scope of USAID.

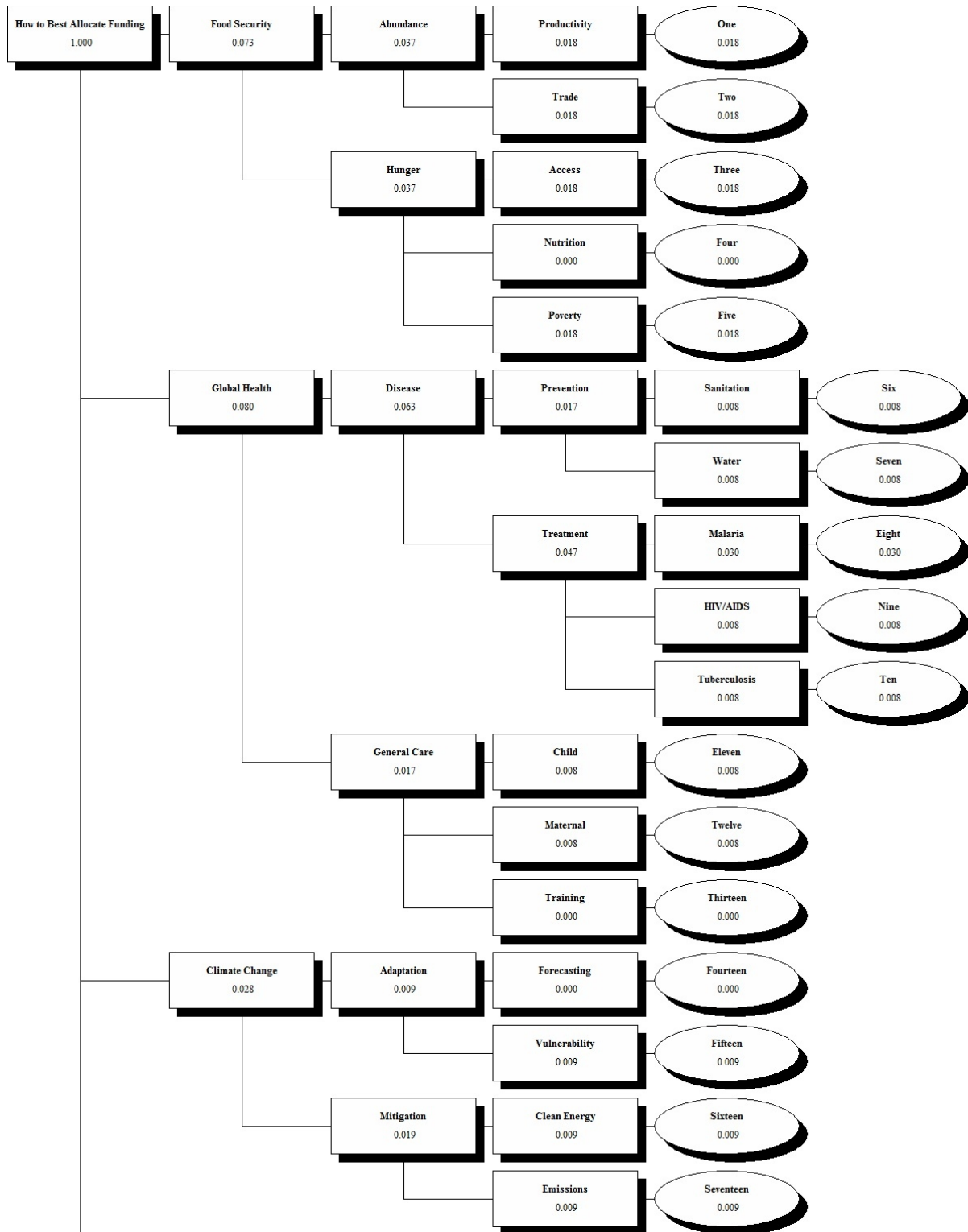
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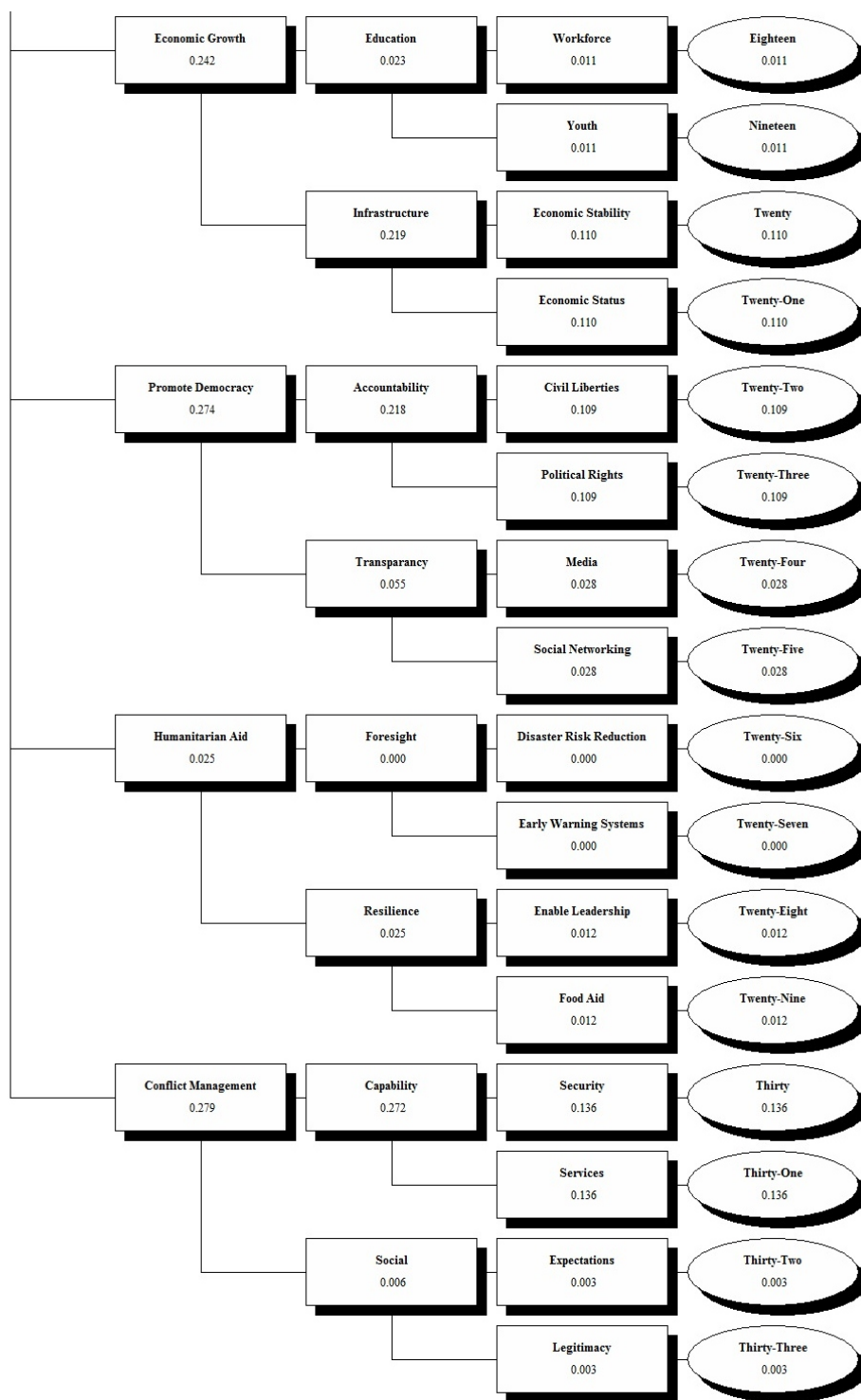
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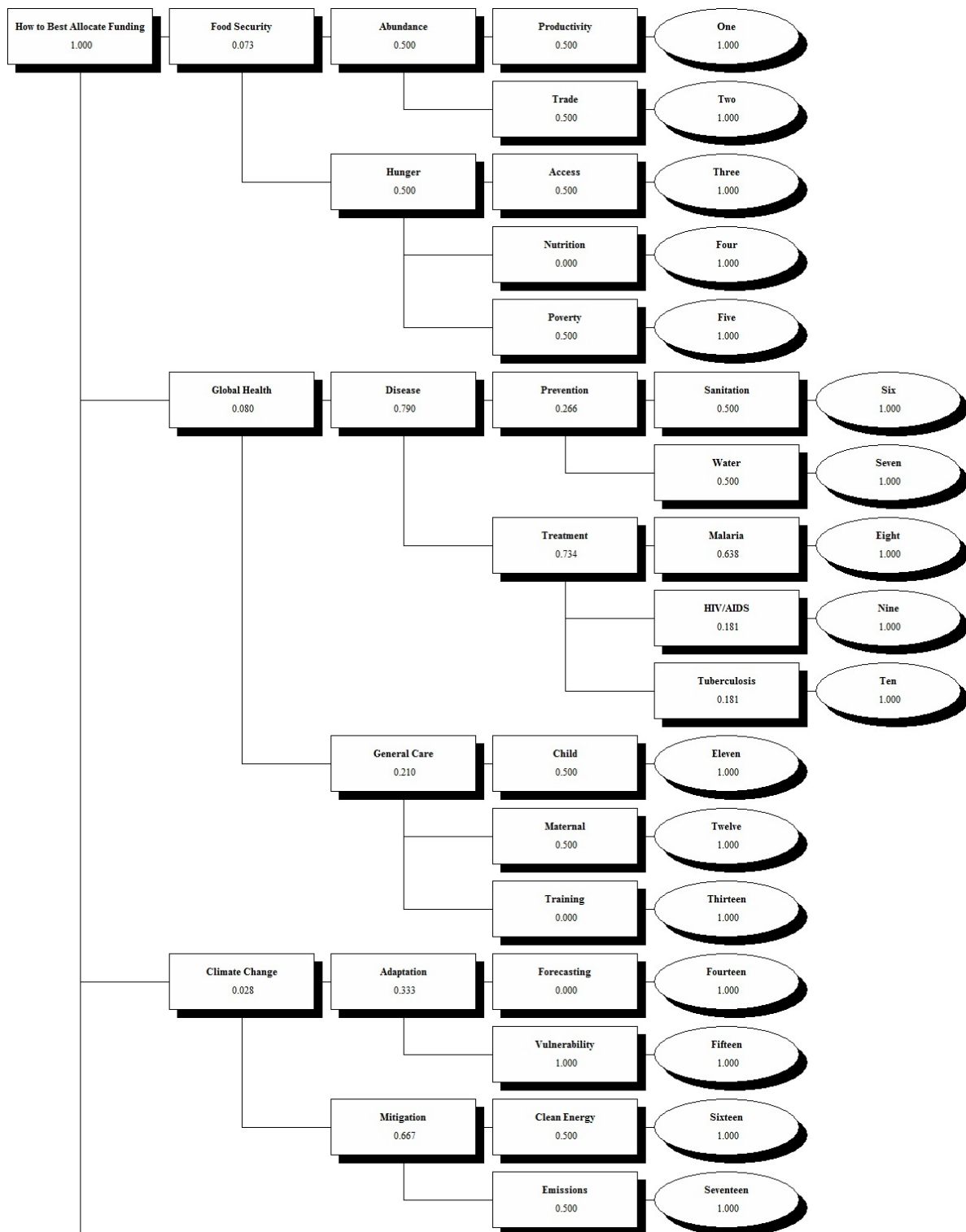


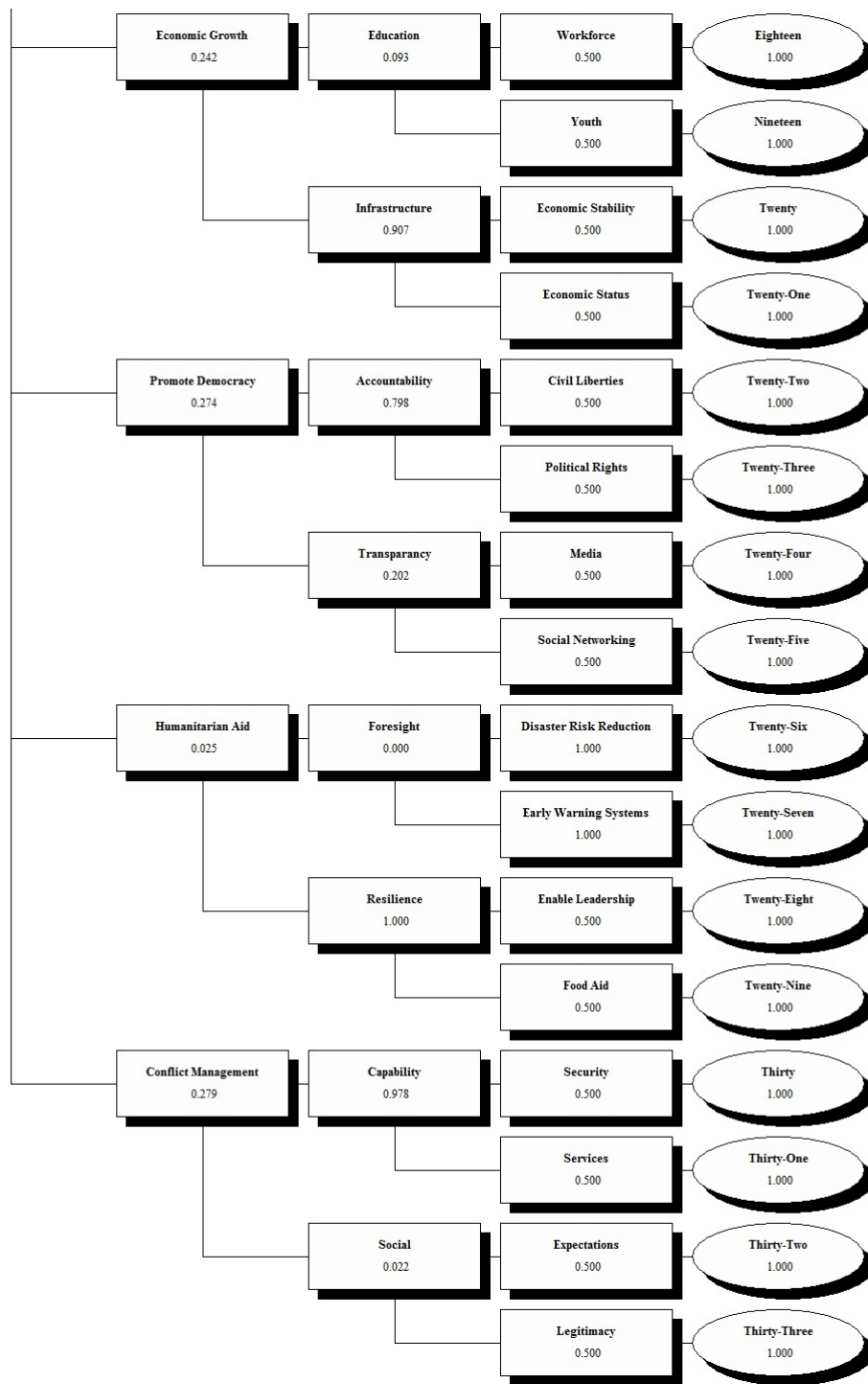
## Appendix A. Value Hierarchy with Global Weights





## Appendix B. Value Hierarchy with Local Weights





## **Appendix C. Measure Definitions**

1. Agriculture, value added (current US\$) (The World Bank, 2012): Agriculture corresponds to ISIC divisions 1-5 and includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Data are in current U.S. dollars.
2. Country Policy and Institutional Assessment (CPIA) trade rating (The World Bank, 2012): Trade assesses how the policy framework fosters trade in goods.
3. Total network of roads in kilometers (The World Bank, 2012): Total road network includes motorways, highways, and main or national roads, secondary or regional roads, and all other roads in a country. A motorway is a road designed and built for motor traffic that separates the traffic flowing in opposite directions.
4. Percentage of population undernourished (The World Bank, 2012): Population below minimum level of dietary energy consumption (also referred to as prevalence of undernourishment) shows the percentage of the population whose food intake is insufficient to meet dietary energy requirements continuously. Data showing as 2.5 signifies a prevalence of undernourishment below 2.5%.
5. Poverty headcount ratio at \$1.25 a day (The World Bank, 2012): Population below \$1.25 a day is the percentage of the population living on less than \$1.25 a day at 2005 international prices. As a result of revisions in PPP exchange rates, poverty rates for

individual countries cannot be compared with poverty rates reported in earlier editions.

6. Percentage of population with access to improved sanitation (The World Bank, 2012):  
Access to improved sanitation facilities refers to the percentage of the population with at least adequate access to excreta disposal facilities that can effectively prevent human, animal, and insect contact with excreta. Improved facilities range from simple but protected pit latrines to flush toilets with a sewerage connection. To be effective, facilities must be correctly constructed and properly maintained.
7. Percentage of population with access to improved water source (The World Bank, 2012): Access to an improved water source refers to the percentage of the population with reasonable access to an adequate amount of water from an improved source, such as a household connection, public standpipe, borehole, protected well or spring, and rainwater collection. Unimproved sources include vendors, tanker trucks, and unprotected wells and springs. Reasonable access is defined as the availability of at least 20 liters a person a day from a source within one kilometer of the dwelling.
8. Prevalence of HIV, total (% of population ages 15-49) (The World Bank, 2012):  
Prevalence of HIV refers to the percentage of people ages 15-49 who are infected with HIV.
9. Reported cases of Malaria (The World Bank, 2012): The number of cases reported is adjusted to take into account incompleteness in reporting systems, patients seeking treatment in the private sector, self-medicating or not seeking treatment at all, and potential over-diagnosis through the lack of laboratory confirmation of cases.

10. Percentage tuberculosis treatment success of registered cases (The World Bank, 2012): Tuberculosis treatment success rate is the percentage of new, registered smear-positive (infectious) cases that were cured or in which a full course of treatment was completed.
11. Under 5 mortality rate per 1000 (The World Bank, 2012): Under-five mortality rate is the probability per 1,000 that a newborn baby will die before reaching age five, if subject to current age-specific mortality rates.
12. Maternal mortality rate per 100,000 live births (The World Bank, 2012): Maternal mortality ratio is the number of women who die during pregnancy and childbirth, per 100,000 live births. The data are estimated with a regression model using information on fertility, birth attendants, and HIV prevalence.
13. Number of physicians per 1000 people (The World Bank, 2012): Physicians include generalist and specialist medical practitioners.
14. Number of observation hubs utilized (USAID Policy Framework 2011-2015, 2011): Creating a global network to provide decision-makers in over 30 developing countries with better climate change and forecasting data, enabling them to make better decisions in a wide range of areas likely to be affected by climate change.
15. CPIA environmental sustainability rating (The World Bank, 2012): Policy and institutions for environmental sustainability assess the extent to which environmental policies foster the protection and sustainable use of natural resources and the management of pollution.
16. Percentage alternative and nuclear energy of total energy use (The World Bank, 2012): Clean energy is non-carbohydrate energy that does not produce carbon dioxide

when generated. It includes hydropower and nuclear, geothermal, and solar power, among others.

17. CO2 emissions in metric tons per capita (The World Bank, 2012): Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.
18. Percentage of total labor force unemployed (The World Bank, 2012): Unemployment refers to the share of the labor force that is without work but available for and seeking employment. Definitions of labor force and unemployment differ by country.
19. Percentage of children enrolled in primary school (The World Bank, 2012): Total enrollment is the number of pupils of the school-age group for primary education, enrolled either in primary or secondary education, expressed as a percentage of the total population in that age group.
20. Percentage of GDP cash surplus/deficit (The World Bank, 2012): Cash surplus or deficit is revenue (including grants) minus expense, minus net acquisition of nonfinancial assets. In the 1986 GFS manual nonfinancial assets were included under revenue and expenditure in gross terms. This cash surplus or deficit is closest to the earlier overall budget balance (still missing is lending minus repayments, which are now a financing item under net acquisition of financial assets).
21. Gross domestic product per capita (The World Bank, 2012): GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making



deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars.

22. Civil liberties index (About Us: Freedom House): The Civil Liberties index measures freedom of expression, assembly, association, and religion. Freedom House rates civil liberties on a scale of 1 to 7, with 1 representing the most free and 7 representing the least free.
23. Political rights index (About Us: Freedom House): The Political Rights index measures the degree of freedom in the electoral process, political pluralism and participation, and functioning of government. Numerically, Freedom House rates political rights on a scale of 1 to 7, with 1 representing the most free and 7 representing the least free.
24. Freedom of the press rating (About Us: Freedom House): The annual index contains the most comprehensive data set available on global media freedom and is a key resource for scholars, policymakers, international institutions, media, and activists. The index assesses the degree of print, broadcast, and internet freedom in every country in the world, analyzing the events of each calendar year.
25. Internet users per 100 people (The World Bank, 2012): Internet users are people with access to the worldwide network.
26. Disaster risk reduction progress score (The World Bank, 2012): Disaster risk reduction progress score is an average of self-assessment scores, ranging from 1 to 5, submitted by countries under Priority 1 of the Hyogo Framework National Progress Reports. The Hyogo Framework is a global blueprint for disaster risk reduction efforts that was adopted by 168 countries in 2005. Assessments of "Priority 1"

include four indicators that reflect the degree to which countries have prioritized disaster risk reduction and the strengthening of relevant institutions.

27. Number of early warning systems accessible (USAID Policy Framework 2011-2015, 2011): Effective ways of predicting, preparing for, and mitigating economic and ecological shocks.
28. CPIA public sector management and institutions average (The World Bank, 2012): "The public sector management and institutions cluster includes property rights and rule-based governance, quality of budgetary and financial management, efficiency of revenue mobilization, quality of public administration, and transparency, accountability, and corruption in the public sector."
29. Depth of hunger in kilocalories per person per day (The World Bank, 2012): Depth of hunger or the intensity of food deprivation, indicates how much food-deprived people fall short of minimum food needs in terms of dietary energy. The food deficit, in kilocalories per person per day, is measured by comparing the average amount of dietary energy that undernourished people get from the foods they eat with the minimum amount of dietary energy they need to maintain body weight and undertake light activity. The depth of hunger is low when it is less than 200 kilocalories per person per day, and high when it is higher than 300 kilocalories per person per day.
30. Intentional homicides per 100,000 people (The World Bank, 2012): Intentional homicides are estimates of unlawful homicides purposely inflicted as a result of domestic disputes, interpersonal violence, violent conflicts over land resources, inter-gang violence over turf or control, and predatory violence and killing by armed groups. Intentional homicide does not include all intentional killing; the difference is

usually in the organization of the killing. Individuals or small groups usually commit homicide, whereas killing in armed conflict is usually committed by fairly cohesive groups of up to several hundred members and is thus usually excluded.

31. CPIA quality of public administration rating (The World Bank, 2012): Quality of public administration assesses the extent to which civilian central government staff is structured to design and implement government policy and deliver services effectively.
32. CPIA social protection rating (The World Bank, 2012): Social protection and labor assess government policies in social protection and labor market regulations that reduce the risk of becoming poor, assist those who are poor to better manage further risks, and ensure a minimal level of welfare to all people.
33. CPIA policies for social inclusion/equity cluster average (The World Bank, 2012):  
The policies for social inclusion and equity cluster includes gender equality, equity of public resource use, building human resources, social protection and labor, and policies and institutions for environmental sustainability.

## Appendix D. Demonstration Single Dimension Value Functions

Value	Type	Shape	Lower Bound	Upper Bound
Productivity	Continuous	Exponential	850	1150
Trade	Categorical	Increment	3.5	6
Access	Continuous	Linear	20329	22391
Poverty	Continuous	S-curve	17	0
Sanitation	Continuous	Exponential	95	100
Water	Continuous	Linear	98	100
HIV/AIDS	Continuous	Linear	0.1	0
Malaria	Continuous	Exponential	25	0
Tuberculosis	Continuous	Exponential	75	100
Child	Continuous	Linear	22.4	14.95
Maternal	Continuous	Linear	14.1	9.87
Vulnerability	Categorical	Increment	3	6
Clean Energy	Continuous	Exponential	21	100
Emissions	Continuous	Linear	1.187	1.068
Workforce	Continuous	Linear	16.5	10.8
Youth	Continuous	Linear	99.6332	100
Economic Stability	Continuous	Linear	-7.757	-1.896
Economic Status	Continuous	Linear	2620.23	3076.09
Civil Liberties	Categorical	Increment	3	1
Political Rights	Categorical	Increment	4	1
Media	Continuous	Linear	55	63
Social Networking	Continuous	Linear	26.39	50.568
Enable Leadership	Categorical	Increment	3.8	6
Food Aid	Continuous	S-curve	400	100
Security	Continuous	Linear	9.027	6.219
Services	Categorical	Increment	4	6
Expectations	Categorical	Increment	4.5	6
Legitimacy	Categorical	Increment	4.2	6

## A Prototype Overview for Allocating USAID Foreign Aid

Capt Deane Cover

21 Apr 2012



### Objectives

- Make a recommendation on how to allocate USAID resources based on a Value-Focused Thinking analysis
- Evaluate current and historical decision alternatives based on USAID and related agency policy
- Develop an overview prototype model for USAID that can be demonstrated on a region or nation-state
- Apply model to the nation of Georgia and draw conclusions that provide insight to a decision maker

### Approach

- Develop a Qualitative Value Model (hierarchy) based on the USAID Policy Framework 2011-2015
- Use the hierarchy and Multi-Objective Decision Analysis to develop a Quantitative Value Model
- Develop prototype model that maximizes value by varying allocation using optimization and regression
- Apply prototype model to region or nation (Georgia)
- Conduct post-model deterministic analysis

### Deliverables

- Prototype overview model that can be applied to any region or nation
- Optimization model that can greatly improve impact by varying any given funding allocation

## **Vita**

Capt Deane Cover graduated from the University of California, San Diego with a Bachelor of Science in Applied Mathematics in June 1996. He received a commission from the Air Force Officer Training School on November 2002. His first assignment was at the USAFA Preparatory School in Colorado Springs. His second assignment was at AFOTEC Detachment 2, Eglin AFB. In August 2010, he entered the Graduate School of Engineering and Management at the Air Force Institute of Technology.

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14. ABSTRACT The United States Agency for International Development (USAID) is the federal government agency primarily responsible for administering civilian foreign aid. In fiscal year 2011, USAID spent approximately \$15 billion in an effort to assist countries recovering from disaster, trying to escape poverty, and engaging in democratic reforms. Using Value-Focused Thinking, regression, and optimization techniques, this thesis utilizes overarching USAID objectives and underlying policy to develop a prototype overview model that is used to provide insight to a Decision Maker regarding how changes in funding allocation can lead to improved impact.					
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U	U	U	UU	79	Richard F. Deckro (937) 255-6565, ext 4325; e-mail: Richard.Deckro@afit.edu